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ABSTRACT

This document outlines the strategies that are used for teaching and assessment in Dominie, an intelligent tutoring system designed to enable the user to operate a computer interface independently. Eight interaction modes are described in detail: four teaching strategies (cognitive apprenticeship, successive refinement, discovery learning, and abstraction) and four evaluation or assessment strategies (practice, direct assessment, discovery assessment, and Socratic diagnosis). Each strategy contains three decisions: (1) the selection of a general area, or, "Select-t-task"; (2) the selection of a teaching strategy for that area, "Select-t-method"; and (3) the selection of a teaching goal, "Select-t-goal." The document follows the format of the control structure, describing each decision step in order of access and then outlining the tutorial and assessment strategies individually. The appendix contains a glossary of terminology used in the document, and a list of additional related technical reports. (7 references) (DB)

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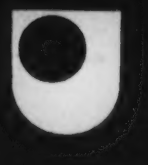

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Computer Assisted Learning Research Group

DOMINIE: TEACHING AND ASSESSMENT STRATEGIES

by Fiona Spensley & Mark Elsom-Cook

CAL Research Group Technical Report No. 74

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DOMINIE:

TEACHING AND ASSESSMENT STRATEGIES

by Fiona Spensley & Mark Elsom-Cook

The work reported here was carried out on ESPRIT project 1613 "Evaluation of an Intelligent Tutoring System Shell for Industrial/Office Training".

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I Glossary of terms

1.0 Introduction

This document outlines the strategies which are used for teaching and assessment in Dominie. To save the reader from having to refer to other documents, this document commences with brief summaries of the knowledge representation and the student modelling in Dominie. The rest of the document follows the format of the control structure, describing each general decision step in the order of access and then outlining the tutorial and assessment strategies individually. There is a glossary in appendix 1 defining the terminology used in this document.

2.0 Knowledge representation [1]

The domain is represented as three types of knowledge. Knowledge about the interface, knowledge about the procedures for operating the interface, and conceptual knowledge about the domain on which the interface is acting.

Interface knowledge is represented as a set of interface actions together with a mapping from these actions into interface tasks.

Procedural knowledge is represented as a list of independent parameterised procedures and a list of tasks. These tasks are the highest level goal of activities which the trainer wishes the student to master. A planner operates upon each of these tasks to produce a plan for achieving that task. The components of the plan are the primitive procedures mentioned above.

The underlying domain knowledge is represented as a declarative network of concepts and associated text. Each procedure is linked to 0 or more nodes in this network.

3.0 Student model and dialogue history.

The dialogue history is a straightforward record of interactions with the student. It is not analysed and forms an unchangeable record of past events. In contrast the

[1] For more details see M. Elsom-Cook & F. Spensley Dominie: Knowledge Representation, Internal Tech. Report, Centre for Information Technology, The Open University (forthcoming).

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student model represents the current state of the student and is continually updated. The student is evaluated after every interaction with the system to see if any alteration is required. The student model has three components: model A which contains confidence ratings for domain dependent knowledge; model B which contains ratings for domain independent knowledge; and model C which contains information on student short term states. Model A is subdivided into knowledge about procedure types and procedure tokens[2], knowledge about concepts and knowledge about interface action types. Models A and B make confidence ratings on the basis of student performance. Model C is based on student's explicit reports.

4.0 Overview of the Control Structure

The control structure must be defined in terms of the choice of interaction style and the choice of topic. The choices of topic area and interaction style/method are not independent, the choice of area depends upon the strategy available and the choice of strategy depends upon what is to be taught. Either way the choice of one constrains the choice of the other, but unavoidably, one decision must be made first.

In Dominie there are four independent teaching strategies and four possible assessment strategies,. This selection of strategies allows the decision as to which interaction strategy to employ to be cut down in two stages. First the decision whether to teach or assess and then, given that constraint, the decision as to which of the interaction methods to choose. Similarly, the choice of area could be subdivided into a broad choice of task, and a specific choice of tutorial goal. This allows for the interleaving of decisions about area and strategy. The control structure in Dominie makes concessions to the interdependence of strategy and area choice by making a broad choice of strategy, then a broad choice of area, then a specific choice of strategy and finally a specific choice of sub-area.

The decision to make the initial choice one of teaching style was in response to information from the field trials of a prototype system. Students did not understand the presentation of the knowledge representation, and therefore had difficulty making decisions about what should be taught next. This was partly due to the limitations of size in the display of the knowledge representation hierarchy on the screens, which did

[2] This is the type-token distinction used by C.S. Peirce (1906). For example typing the letter 's' on the keyboard is a 'type' of action, tokens of which are an instance of typing 's' in 'this',an instance of typing 's' in 'distinction' etc.

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not provide the necessary overview. It was concluded that presenting the knowledge representation to the student in that form was not a useful part of the skill acquisition process, and students did not understand the representation enough to take full advantage of the choice of tutorial area it offered them. Therefore the initiative in area selection has been left with Dominie. Students felt that they wanted to decide whether or not to be assessed, the prototype was rigid in its presentation: teach always being followed by assess. In contrast Dominie allows students to take the initiative here and superimpose their own choices as to whether the next step should be teach or assess. The choice will be made for them if they do not express a preference at this stage, with reference to the state of the student and the prior interaction. At the same decision point students will be presented with three additional options: to revise material, to browse forward to look at unpresented material, or to quit the system. These options were requested by students in the field trials and they allow the student to have more control over the course of their tutorial session.

The control structure has a fine granularity, modelling the student after each step in the interaction, ie. after each teach or assess action. The continual monitoring of the student's progress allows full exploitation of the flexibility that having a choice of strategies provides, and satisfies a major consideration in the design of Dominie: to be as responsive as possible to the state of the student, and to explicit requests from the student..

The rules will be expressed in prolog and there is an implied backtracking if lower level decisions are not consistent with the earlier decisions. Dominie will not backtrack on the initial set-interaction-style decision as the student may have made an explicit request here, and it would be confusing if having chosen 'assess' the student was then taught. If a students choice is inconsistent, they will be presented with the set-interaction style decision again, Dominie having cycled once round the control structure.

The control structure is illustrated in figure 1 below as a state transition diagram and described below it in terms of prolog-format rules. The next sections follow the terminology in these rules.

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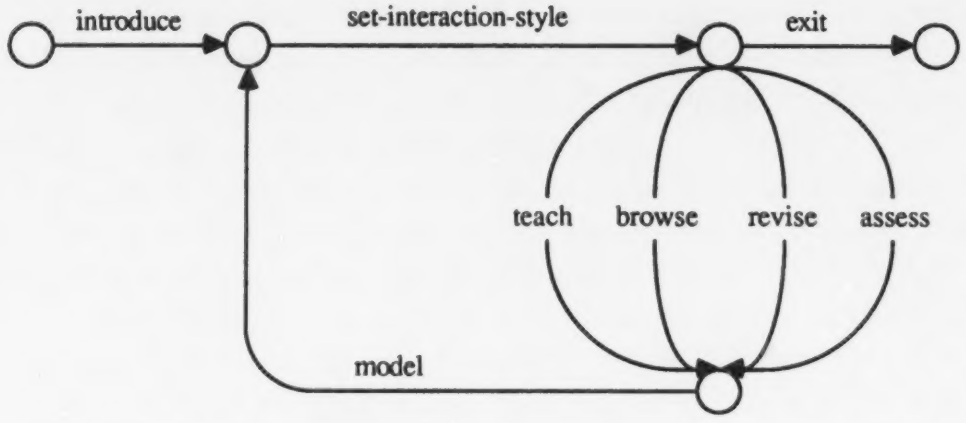

Figure 1 Control Structure for Dominie

Control Structure rules

Dominie if	Introduce and Tutor
Tutor if	Set -interaction-style and Interact and Model

Set-interaction Style

Interact if	Teach or Assess or Browse or Revise
Teach if	Select-t-strategy and Present-teach
Assess if	Select-a-strategy and Present-assess

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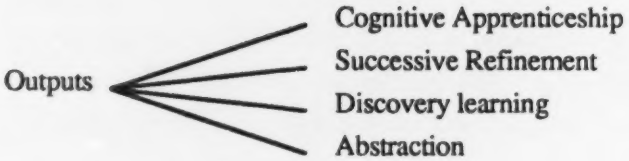
Select-t-strategy if

Select-t-task and
Select-t-method and
Select-t-goal

Select-t-method



Select-a-strategy if

Select-a-task and
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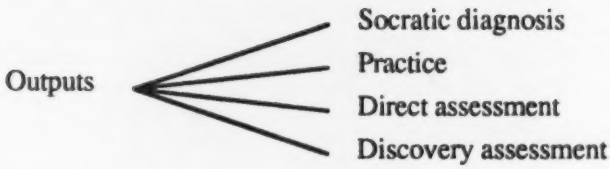
Select-a-goal

Select-a-method



4.1 Introduce

The introduce step is called only at the beginning of a tutorial session, it presents an introductory text describing the Dominie system. This introduction will aid subjects understanding of the system by countering the problems found by subjects in the field trials: they found that the workings of the system were not apparent, and that many of the terms used in the text were not clear. A long introduction will be presented the first time a student uses the system. On subsequent sessions students will be presented with a summary and given the option of reviewing the full version if desired.

The introduce step also retrieves the old student model and dialogue history if the

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user has previously interacted with the system, or sets up an empty dialogue history and student model if the user has not.

4.2 Set-interaction style

The set-interaction style rules output a decision to either teach, assess, browse, revise or exit. In the prototype an assess action always followed a teach action. This rigidity (disliked by subjects in the field trials) is avoided in Dominie by having a more elaborate decision process and by allowing the student to specify her desires directly. At the set-interaction-style decision point the student will be able to choose any of these options by selecting them from a menu. If the information from the student model (model C) indicates an appropriate student state (eg. confusion, boredom) Dominie may suggest the use of browse or revise facilities to the student, but they will never be invoked directly by Dominie. Similarly the student is free to choose to exit at any point, but Dominie will only select exit when all the material is both taught and known .

If the initiative is left with Dominie, a teach, assess or exit decision is made. The decision depends on information from the dialogue history about the last strategy used and the knowledge state of the student (model A). If the student is just commencing her interaction with the system, she must be taught, as there is nothing to assess . Equally obvious is the decision to exit if she knows everything that the system has to offer. The procedural knowledge is organised into tasks, and each task will be fully taught and assessed before moving on to the next task. When a new task is entered the system will begin by teaching. Priority is always given to reteaching if the student appears to be failing consistently. In general Dominie will continue with the same teaching strategy if the student is progressing well, and make a teach or assess decision relative to that strategy.

4.3 Teach

When the decision to teach has been made, the particular teach strategy must be chosen (Select-t-strategy) and then that strategy must be executed (Present-teach). The selection of a strategy involves three distinct decisions: the selection of a general area (Select-t-task), the selection of a specific teaching strategy for that general area (Select-t-method), and the selection of a specific teaching goal within the task area for teaching

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by the selected strategy (Select-t-goal). The selection of the specific teaching goal depends on the strategy chosen and the criteria will be presented in the context of the individual teaching methods. As will the procedures for Present-teach which are also method-specific.

4.3.1 Select-t-task

In the knowledge representation the tasks are represented as a top level list. Select-t-task will work from left to right along this list, and then loop back to the beginning again. Dominie will teach and assess each task to completion before moving on to the next task.

An important consideration in selecting a task for teaching is to ensure that reteaching occurs at suitable points. Primacy is therefore given to reteaching if the student has been consistently unsuccessful. If the last two assessment steps were assessed and the student failed, then the task will be set to that area . This rule is identical to one used in set-interaction-style to set the teach option and can be viewed as passing a reteach request down the control structure. This allows for immediate response to extended confusions in the student, without over-reacting to individual errors that may just have been slips, not requiring immediate reteaching. Once a task has been completely taught it is checked for isolated reteach flags. This invokes the reteaching of the occasional errors, and responds to any reteach flags entered by the student herself during a revision phase. The rules do not allow the student to enter a cycle of continual reteaching of a goal, which she consistently fails to master. If the unknown goal has recently been retaught it will not be retaught again until a later stage, when the student may have gained a better framework within which to assimilate the problematic procedure.

4.3.2 Select-t-method

Select-t-method determines which of the teaching strategies should be employed, cognitive apprenticeship, successive refinement, discovery learning or abstraction. These decisions depend on the current task and the dialogue history. In general it will choose to continue with the same method if the task is the same and the student seems to be progressing well. The exception is for discovery learning which will always be

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used if appropriate. This allows bright students to save time by avoiding material which might appear repetitious (see section 5.3 for strategy details). Priority will be given to any reteaching that is necessary, and reteaching will always be by a different tutorial method. If there is no external information indicating a particular strategy it will assess the suitability of the alternatives from the most specific to the least specific, the default being cognitive apprenticeship which is always applicable.

4.3.3. Select-t-goal

The selection of a goal within the selected task is determined by the teaching method chosen. The rules for select-t-goal are outlined and discussed under the different teaching method headings in section 5 below.

The one aspect of select-t-goal that applies to all the different methods is the rules for reteaching. Reteaching will be invoked when the last two assessments were failed, or when model C indicates a confused state, reteaching the areas marked as "unknown" will then be given priority so that existing problems are sorted out before moving on to new areas.

4.3.4. Present teach

The presentation of tutorial material depends on the teaching method chosen by select-t-method. It is discussed in section 5 in the appropriate sub-sections.

4.4 Assess

The assess procedure operates in a directly analogous way to the teach procedure (section 4.3 above). A task is selected first (select-a-task), followed by the choice of assessment method (select-a-method). The rules that follow, for selecting the specific assessment goal (select-a-goal) and for presenting the assessment materials (present-assess) are then local to the method selected, and are discussed under the methods. When the decision to assess has been made, the particular strategy must be chosen (Select-a-strategy) and then that strategy must be executed (Present-assess). This process is analogous to that following the teach decision.

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4.4.1. Select-a-task

As with select-t-task the tutor works from left to right along the list of tasks and then loops back to the beginning again, evaluating the suitability of each task. Similarly each task is assessed fully before moving on to the next task. If all the tasks have been assessed the task which contains goals which are not known is chosen.

4.4.2 Select-a-method

Select-a-method determines which of the assessment strategies to use, Socratic diagnosis, direct assessment, practice or discovery assessment. It allows for the pairing of particular assessment strategies with particular teaching methods, cognitive apprenticeship is always initially assessed by practice, and discovery learning is always followed by discovery assessment If the student is progressing well, the same assessment strategy is maintained for the whole of a given task.

4.4.3 Select-a-goal

The selection of a goal within a task is determined by the assessment method chosen. The strategies for select-a-goal are outlined and discussed under the different assessment method headings in section 5 below.

4.4.4 Present assess

The presentation of the assessment material depends on the assessment method chosen by select-a-method. This is discussed in detail under the heading for each individual method in section 5 below.

4.5 Revise

Revision is used to review what has been presented so far. It offers the student the option of a summary of "where they are" in terms of high level tasks, and lower level procedures within the current task. The revision interaction style functions apart from the normal teaching and assessment modes, and will not affect the student model. The student is able to have a look at the material that has been taught at any stage by moving

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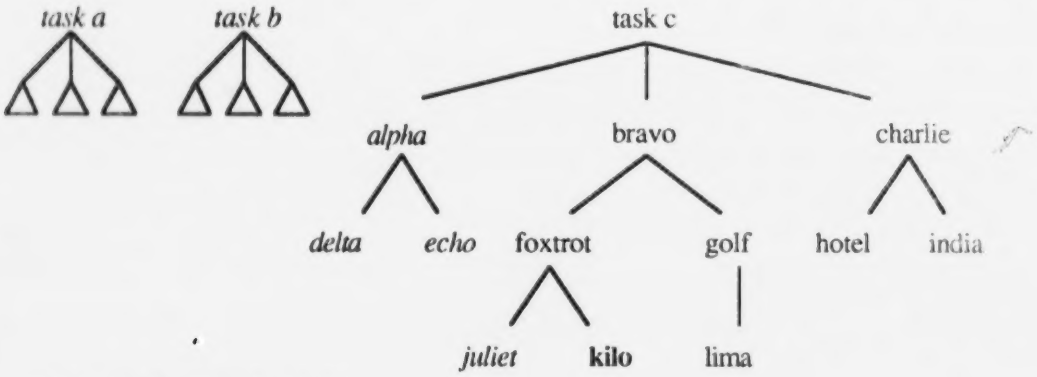
backwards through the knowledge representation. Revision is sensitive to where the student is in the knowledge representation, by using the dialogue history to find the last task taught. If the student is at a particular procedure within a task, that task will be revised by summarizing the procedures learnt up to that point. It will also summarise previous tasks taught, but only in terms of their top level goals. The student can then ask for more details for any of these. If more details are requested for a procedure within the same task, revise will repeat the tutorial presentation last made for that material. If more details is requested of a previous task, the task will be broken down into its constituent procedures, which can then be reviewed individually in terms of the previous action. When a detailed description is given for a specific procedure, revise will show the tutorial material for that procedure that is associated with the teaching method that was last used to teach it, ie. if it was taught by successive refinement it will be revised using successive refinement.

While moving through previously taught material the student will also be able to ask to be retaught any procedures that they feel unsure about. This covers the students memory lapses, they may forget material that the user model may have recorded as known. These 'flagged' procedures will then be retaught at a later stage by a different teaching method than that originally used.

An example of revision.



last procedure taught - **bold**
taught procedures - *italic*
untaught procedures - plain

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If the student requests revision after the *kilo* procedure within task c, Dominie will respond:

"You have just learnt to kilo, and to juliet. Before that you learnt to delta and echo and alpha. These are all subparts of task c. Before that you learnt task b and task a."

Dominie will then ask the student if she wants any more details on any of the procedures or if she wants to return to the tutorial session. If more details are requested, areas are then selected by the student for re-presentation.

4.6 Browse

The browsing mechanism will operate in an analogous way to the revision method. It will present a summary of the procedure, to tell the student "you are here", but offer the facility to browse forward rather than to review backwards. The browsing interaction would involve presenting summaries of the material, similar to the revision material, and then using the cognitive apprenticeship texts and demonstrations if further detail is requested. As the facility is just a browse mechanism, there should be no restrictions on what the student sees, and there need be no control over the appropriateness of the materials. The student may see material that she cannot understand fully, but this should be anticipated and therefore not be a problem for students. When the student exits from browsing, the system will return her to the point at which browse mode was invoked.

4.7 Model

Modelling of the student follows every interaction whether Teach or Assess etc., although there is no updating of confidence levels for the specific areas browsed or revised. This is because the motivation for engaging in these activities would vary from student to student. Revision might be engaged in by a confident student to ensure that she remembered everything, or used by a confused student to try to make sense of previous procedures. Equally browsing might indicate a constructive lookahead strategy or merely boredom.

The modelling phase also allows students to indicate a short-term state by

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indicating the prescence or absence of felt states presented to them as options. A piece of text is produced in response. This may direct the student to a particular course of action in the set-interaction phase that follows. eg. If the student indicates confusion, then reteach. The model C value is removed from the student model when Dominie has responded appropriately to it, this eliminates the problem of the duration of these short term states. Both the modelling and response to short term states is very primitive in Dominie although this aspect could be extended in future versions of the system.

Modelling of procedural and conceptual knowledge is also context and question dependent. Asking students to perform a procedure immediately after they have been shown it will not give cause for great confidence in their ability to perform that procedure. If the same request is made after a considerable gap between teaching and assessment, performance becomes the ultimate test of a procedural skill. For direct assessment, questions will be generated of varying difficulty level and will be evaluated appropriately. Discovery learning will be assessed according to how many hints were offered before solution.

5. Teaching and Assessment Strategies

Overview of the teaching structure

The overall goal of Dominie is to enable the user to operate a computer interface independently. When the system is satisfied that the user can perform the necessary procedures, and has an understanding of the conceptual basis of the skill, the teaching is completed.

Dominie supports a total of eight interaction styles, four teaching and four assessment strategies. It operates by teaching initially from the basis of the procedural representation, taking this either bottom up from basic level skills (cognitive apprenticeship) or top down in terms of task structure (successive refinement). The latter also introduces some conceptual information and the former will provide it on demand. Where a procedure is analogous to one previously presented discovery learning is always tried. This allows students to spontaneously generalise from known procedures. The final teaching strategy is abstraction, which teaches the conceptual information, once the procedural basis is known. This ensures subjects gain an

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overview of the whole process in terms of the underlying concepts. All the procedures and concepts taught using these strategies are assessed at some stage, not necessarily immediately after they were taught. Cognitive apprenticeship and discovery learning have specific assessment methods: practice and discovery assessment respectively. Practice is also used to check on procedural performance at other stages Direct assessment allows for the assessment of any type of knowledge taught using declarative questions. Finally socratic diagnosis allows for problems to be found, it allows for a review of previous student assessments to cover students forgetting, or becoming confused after prior performance had been correct. Each interaction step causes the student model to be updated, and in addition an assessment may result in 'reteach flags' being left. If reteaching is required it is always by a different teaching method, with the limitation that discovery learning is never used for reteaching. This is due to fact that discovery learning is the least supportive teaching strategy.

These eight strategies are in addition to the revision and browsing facilities (outlined in sections 4.5 and 4.6), which allow the student flexibility in looking at any of the material without being taught or assessed. These may have an incidental teaching effect, but this cannot be easily modelled.

The table overleaf summarizes the differences between interaction styles in their coverage of the domain.

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Method	Style	Procedures	Concepts
Cognitive apprenticeship	teach	yes	on request
Successive refinement	teach	yes	yes
Discovery learning	teach	yes	no
Abstraction	teach	no	yes
Practice	assess	yes	no
Direct Assessment	assess	yes	yes
Discovery Assessment	assess	yes	no
Socratic diagnosis	assess	yes	no

5.1 Cognitive Apprenticeship

There is currently a trend with some tutoring system groups in America to use a technique known as 'cognitive apprenticeship' (Collins & Brown in press). This is based on the idea that cognitive skills can be learnt as crafts were learnt from an expert in that craft. The tutor demonstrates the skill and allows the pupil to ask questions at any point in the demonstration.

This teaching procedure allows students to watch a step through demonstration of a procedure, with associated verbal explanations. It begins with the low level actions to be performed, showing how each is performed and then building a model of the overall task on top of these basic procedural skills. This is in contrast to the 'top-down' approach of successive refinement (section 5.2) which starts with the conceptual basis

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of the skill.

Cognitive apprenticeship operates on the same principles as a traditional apprenticeship. The student is watching and imitating an "expert" performing the task. This structure is achieved in Dominie by always following the cognitive apprenticeship demonstrations with practice assessment (section 5.5). In the description of the task below the two procedures are described as they will appear to the student, to give a taste of the cognitive apprenticeship method. Within the control structure, Dominie will be modelling the student after each demonstration and each imitation step, although this will not be apparent to the student.

In cognitive apprenticeship Dominie will begin by presenting the superordinate goal to the one to be taught (if it has not already been presented). This is a series of steps at the level above that which it expects the student to imitate. This provides a context for the action. It will then present the relevant sub-steps one by one. It will perform a step and then ask the student to repeat the action (practice assessment). Using the dialogue history to provide continuity, a series of tutorial steps will involve the student in performing all the sub-steps of the goal initially demonstrate, in order, before being asked to perform the higher level goal.

During the course of the teaching session students will be able to request further information. They can get explanations of concepts that have been encountered in the accompanying text, by accessing the conceptual representation.

Given a task area, this teaching strategy will start at the lowest level of student knowledge. If nothing is known it will begin by demonstrating the task one level above the relevant basic actions, and then asking the student to perform the basic steps. All the basic actions must be marked as known in the student model if it is to teach at the level above this.

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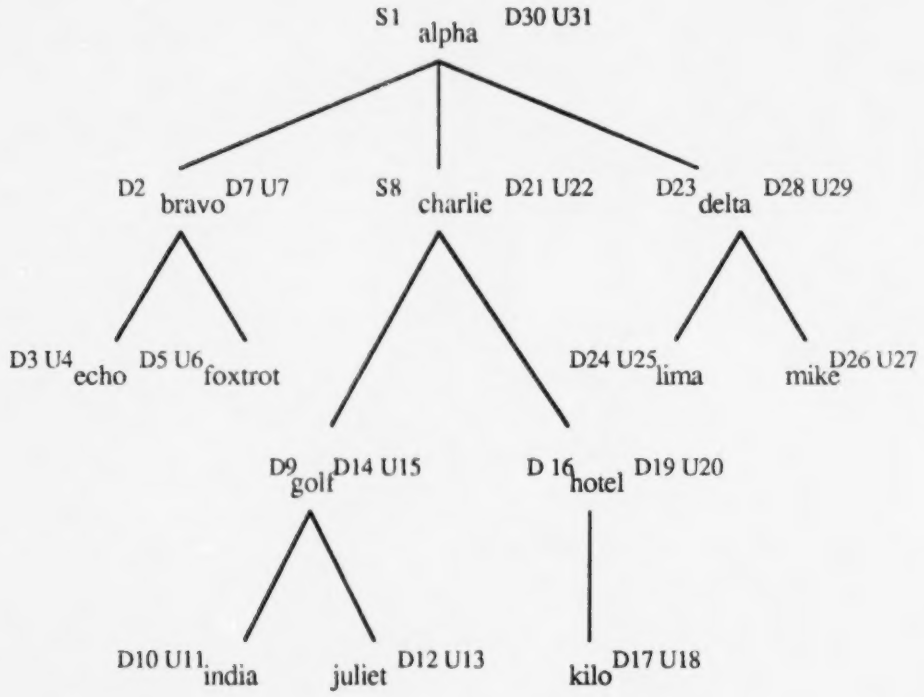
An example of Cognitive Apprenticeship:



Numbers indicate sequence
D indicates demonstration by system
U indicates user performs task
S indicates summary

Order of Cognitive Apprenticeship

If the system is given the untaught task alpha to teach using cognitive apprenticeship, it will see that it cannot immediately teach that node. It will therefore search down the task representation to find a suitable goal, in this case bravo (the first unknown non-basic procedure).

The system will then demonstrate bravo (ie. both echo and foxtrot in sequence). Having done that it will demonstrate echo with accompanying text and ask the student to imitate it. It will then do the same for foxtrot. After that has been achieved

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successfully it will demonstrate bravo again and ask the student to imitate this higher level goal which includes the subgoals just demonstrated, in sequence.

Having successfully learnt bravo the system will evaluate charlie. This node is too high level for a student with no previous knowledge, so it will search downwards to find golf.

The system will then demonstrate golf, teach india and juliet, then teach golf. It will then demonstrate hotel, teach kilo, then teach hotel and subsequently teach charlie. When it has also taught delta and its subnodes, Dominie will finally teach alpha.

5.2 Successive Refinement

Much of the material which the system is likely to teach will have many ramifications and consequences which the pupil will ultimately need to understand. If all this material is presented on the first pass with a student, the student is likely to be overwhelmed. Instead, this interaction style operates by making selective passes through the material introducing new detail on each pass. This is in line with the ideas on successive refinement advocated by A.N. Whitehead (1932).

In the tutor, this is effectively a self-contained teaching strategy. It can be applied to any area which is not a basic procedure. It can be used for first-time teaching or reteaching. It is not linked to any particular form of assessment of the pupil, and will generally be used in a continuous teaching sequence for a given task before any assessment is carried out, unless the student requests assessment.

Having selected an area to teach, a summary overview of the problem is presented, followed by the conceptual information associated with the task. Increasing levels of detail are presented as the system works down the tree.

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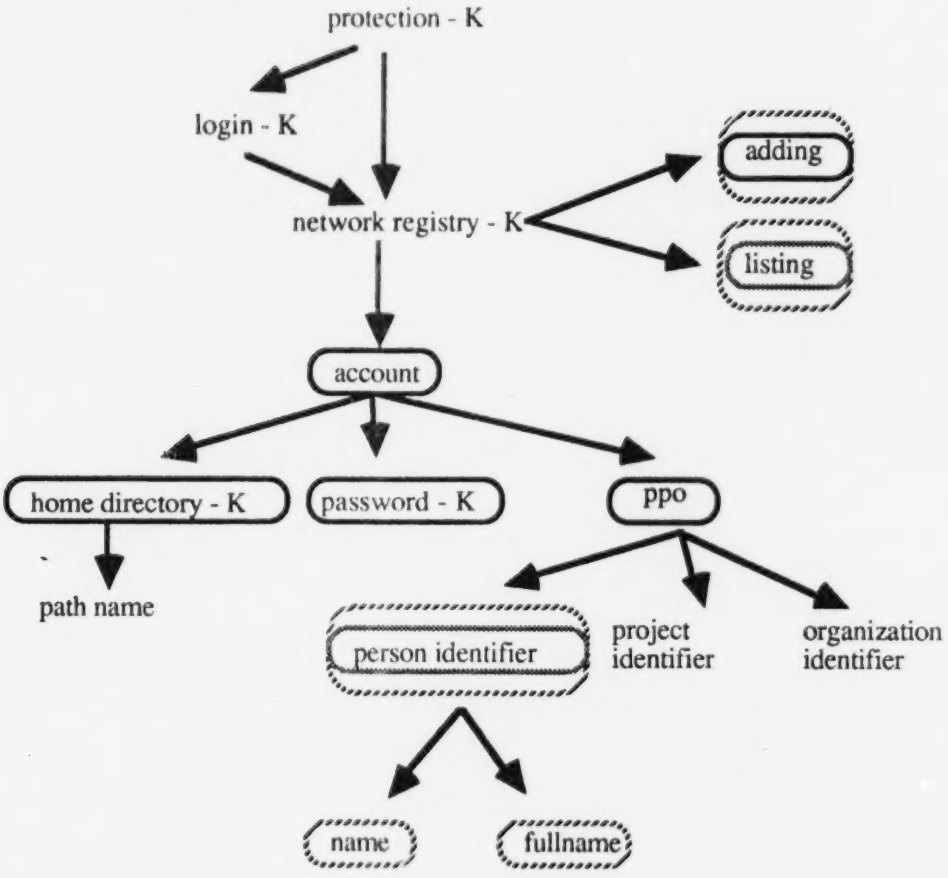

Example of the selection of declarative information for a goal

The diagram above shows a network of concepts and their links to the relevant procedures[3]. It also shows which concepts have been previously presented to the

[3] For more details of the conceptual representation see M. Elsom-Cook & F. Spensley Dominie: Knowledge

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student and are marked as known. To present the conceptual information associated with the procedure to evaluate person exists, all the nodes linked to evaluate_person_exists will be selected, ie. adding; listing; person identifier; name ; full name. These will then be followed back up the tree, in all cases until they reach network registry which is a known concept. This will produce five subnets. One from 'adding' back to 'network registry'; one from 'listing' back to 'network registry'; one from 'person identifier' back to 'network registry'; one from 'name' back to 'network registry'; and one from 'full name' back to 'network registry'. The latter three overlap to a considerable extent, and all five share the 'network registry' node. For presentation the duplication will be eliminated and the network of concepts will be rationalised to form the one network illustrated overleaf.

This will be presented from network registry downwards. 'Network registry' will be presented as a summary[4] (as it is already known), then 'account' will be presented, then 'ppo', then 'person identifier', then 'name', then 'full name', then 'listing', then finally 'adding'.

Representation, Internal Tech. Report, Centre for Information Technology, The Open University (forthcoming).

[4] When summaries are presented students will be able to request the full text if they wish.

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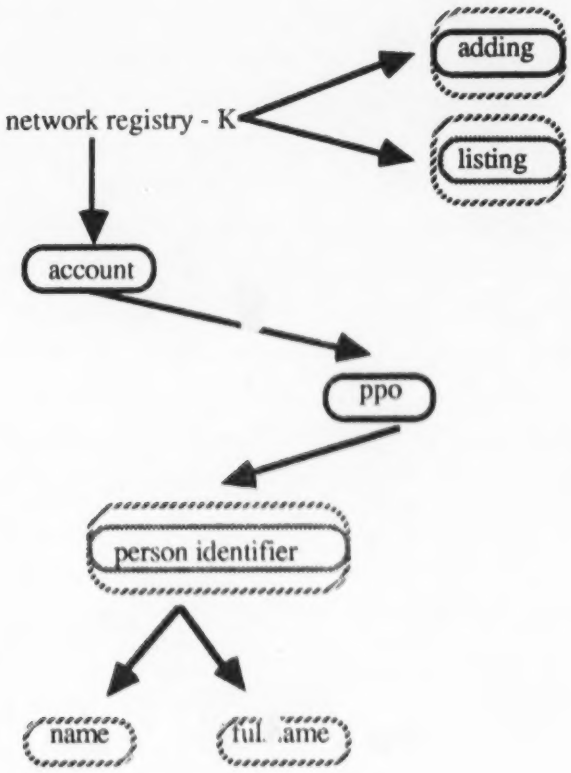

Linked to create_new_account

Linked to evaluate_person_exists (1)

Linked to evaluate_person_exists (2)

K Known by subject

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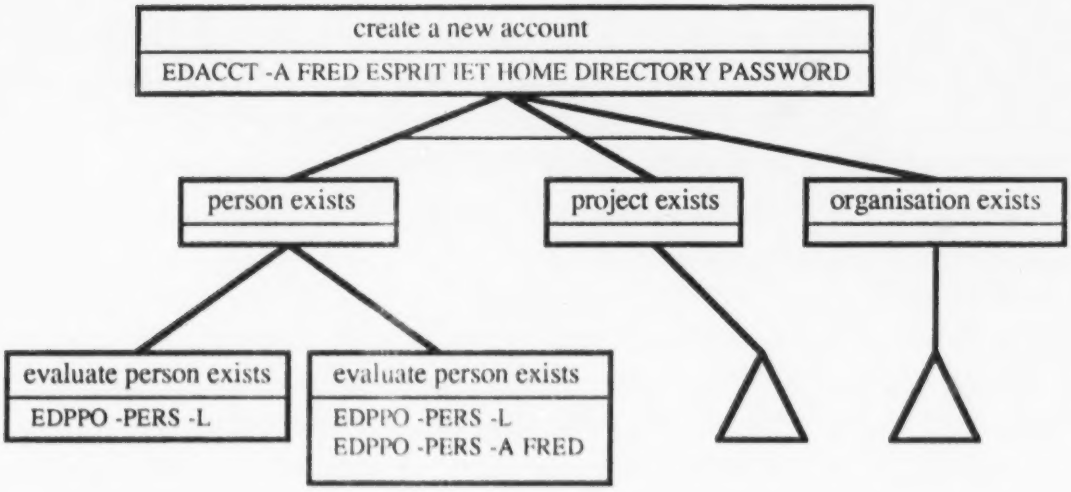

Partial plan for adding an account

If we have the plan shown above, and our top-level goal is adding an account, then the successive refinement strategy will operate on the procedural part in the following way:

" The goal is to create a new account. In order to create a new account it is necessary to ensure that the person, project and organization identifiers exist. When these preconditions have been satisfied, we can achieve the goal "create a new account" by typing 'EDACCT -A FRED ESPRIT IET HOMEDIRECTORY PASSWORD'."

Dominie will then introduce the associated conceptual information before presenting the "person exists" node in a similar way.

5.3 Discovery Learning

The discovery learning approach involves putting a student in a situation in which she does not actually know the correct form of behaviour, and helping her to find the appropriate behaviour for herself. Obviously this is not appropriate for all students, and is only suitable for certain materials. In the domains in which this tutoring system operates the most useful application of this technique is helping people to learn to generalize by placing them in new situations which are analogous to ones which they

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have met before.

This teaching strategy is always followed by discovery assessment (see section 5.8). Discovery assessment monitors a student's solution attempts and if the analogy is not immediately apparent guides the student towards a solution by giving her hints based on the known analogous procedure.

A major component of the tutor's task during discovery learning is the selection of an appropriate problem. In the case of this tutoring system, we are seeking analogies between tasks. Two goals can be regarded as being analogous if they involve the same procedure parameterised in a different way. For example, In the domain of adding an account to the Apollo, there is a clear analogy between checking that a person identifier exists and checking that a project identifier exists. The search for a suitable goal is carried out 'top-down' within the task so that any analogy is recognised at the highest possible level (all the sub-procedures will then, necessarily, be analogous[5]).

Dominie will apply discovery learning when teaching any analogous task for the first time. This allows students who recognise the analogies to avoid being taught procedures which will appear obvious to them, having already learnt them in a different context. This avoids frustrating repetitions and encourages able students to progress at a faster pace. Once a goal has been tried with discovery learning (and failed) Dominie will not use it again for that goal. This ensures that students who do not respond well to this teaching method receive a more supported introduction to the topic.

An example of a Discovery Learning/discovery assessment interaction is given in section 5.8.

5.4 Abstraction

The teaching strategies discussed so far present their tutorial material in the context of specific procedural tasks. Taking them either top-down (successive refinement) or bottom-up (cognitive apprenticeship). It is important to provide students with a global view of the task contexts in terms of the concepts which underly the whole skill, cutting across task boundaries. This allows students to elaborate their model of the task

[5] For more details of the plan structure see M. Elsom-Cook & F. Spensley Dominie: Knowledge Representation, Internal Tech. Report, Centre for Information Technology, The Open University (forthcoming).

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(provoking deeper processing and therefore longer retention of the skill), and to generalise across task boundaries.

Abstraction makes *explicit* links between all the known procedures, from the conceptual perspective. This serves a different function from discovery learning which attempts to get the subject to make their own connections on the basis of procedural similarity (this also helps those who did not like discovery learning). As well as explicitly encouraging students to generalise their procedural knowledge in terms of the underlying concepts, the abstraction strategy ensures that all the conceptual information will have been presented to the student. Tasks successfully taught by cognitive apprenticeship or discovery learning will not have had the associated conceptual information presented, unless the student had made a request for further information during the interaction.

Abstraction differs from the successive refinement strategy, as the latter assumes that the student has no knowledge of the procedures and operates by providing 'conceptual hooks' on which to hang her knowledge of the procedures. In contrast the abstraction strategy allows students to generalise about procedures and form a unified view of the task once they have learned how to perform the procedural tasks.

The abstraction strategy will only be called when a task has been completely taught. It then works by tracing the links from all the procedures within the task to the conceptual representation, and generating a weighted net (in a similar fashion to that generated in successive refinement). This net will then be given an additional weighting in terms of the number of individual procedures that are linked to the individual concepts.

Presentation will start from the node with the most procedures associated with it, and move from the most specific to the more general. The abstraction strategy will present the conceptual information in summary or expanded form (depending on whether the student knows that concept) and then outline the links to procedure types (to avoid repetition with procedure tokens) using the text associated with the concept to procedure links in the conceptual representation.

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5.5 Practice

This assessment simply asks the student to perform the action associated with a goal that she has been learnt. The student will be presented with a specific example of the procedure and the appropriate screens on which to perform the action. She will also have the facility to ask to be shown the next step when she is performing a whole sequence of actions (ie. non-basic procedures). If the student performs the task incorrectly, Dominie will tell her and demonstrate the correct procedure. This strategy will always follow cognitive apprenticeship, but may also be used after other teaching strategies.

5.6 Direct Assessment

Direct assessment involves presentation of questions to the pupil to test their declarative knowledge of concepts and procedures. The questions used in the direct assessment will be of the multiple choice form or in terms of slot filling. This allows for the automatic generation of questions, and overcomes the problem of typing errors and other simple slips which occur with constructive response questions and prove frustrating to students. Direct Assessment should be able to explain the correct response when the student makes an error, and recognise when the student selects or produces a "near miss" response, eg. selecting the parameter associated with a parallel procedure.

Direct assessment will be invoked after an area has been presented, by any method, but will be particularly aimed at assessing conceptual knowledge. Whatever the area, direct assessment will operate a depth first search and assess from the most basic level procedures that are not known. That is, either a basic level procedure or a level above anything which is known with a high degree of confidence. The assessment method prompts students to answer questions appropriate to their level.

5.7 Socratic diagnosis

Socratic teaching involves the systematic breaking down of a student's proposed (incorrect) solution to a problem. The teacher identifies the error and through a series of appropriate questions guides the pupil to recognise inconsistencies and realise her

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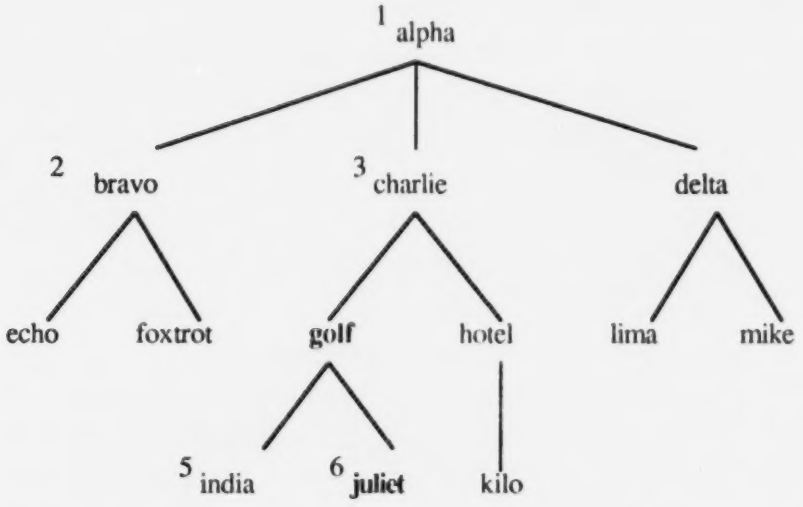
own errors. This process forces the pupil to consciously think about the problem and about where the problem in the proposed solution lies. The interactive nature of this process is important, because the student is likely to try and pursue lines of reasoning which will not lead to identifying the error for herself, but rather towards confirmation of her erroneous hypothesis (Wason 1977).

When practical use of 'socratic' tutoring is made in Intelligent Tutoring Systems, the full power of the technique is not applied since the necessary sophistication of user modelling has not yet been achieved. Instead it is taken to indicate a systematic decomposition of an error into analyses of the subskills until the underlying error has been identified. This is the technique used in TRILL (Cerri 1983) and WHY (Stevens, Collins & Goldin 1982), for example.

Socratic diagnosis will be invoked in Dominie when an error has been detected in the performance of the student. It operates from the highest level goal where a problem has been detected. It then breaks down the problem to see if there are problems with



Bold - misconception

The Socratic Search Strategy

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any more fundamental procedures. This allows for misconceptions that had allowed a student to progress for a while to be found out, and also allows for forgotten procedures to be discovered and retaught.

The strategy is described with reference to the diagram above, as it would appear to the student. In terms of the control structure, the student is modelled after each goal is assessed and continuity is maintained by referring to the dialogue history. In terms of the overall strategy it applies the node evaluation process recursively.

To illustrate this, let us assume that the pupil has incorrectly attempted the procedure associated with *alpha* in the diagram. Let us further assume that this is due to one misconception about the basic procedure *juliet* and a second misconception about the procedure *golf*.

The tutor will ask the student a question about *alpha* which she will fail to answer correctly. The tutor then asks about *bravo*, which the student deals with correctly, and then *charlie* which the student answers incorrectly. The next question is about *golf* (which is answered wrongly), then *india* (which is answered correctly) and finally *juliet* which is answered incorrectly. Since this is a basic procedure, the tutor reteaches it and updates the student model. Returning to *golf*, another question is asked which still leads to an error. The children have been assessed, so the node is retaught and the system returns to ask a question about *charlie* and then *alpha*.

5.8 Discovery Assessment

Discovery assessment always and only follows discovery learning. The assessment consists of asking the student to perform the procedure associated with the goal (as in practice assessment) and offering them guidance based on an analogous procedure. If the student does not know what to do she can ask for a hint, by clicking an icon on a hint menu (this just contains the entries "hint" and "quit").

In the domain of adding an account to the Apollo, there is a clear analogy between checking that a person identifier exists and checking that a project identifier exists. In the case where the student has learnt the former but not the latter, the interaction would be something like:

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Presentation:

" I'd like you to try and find out how to test if a project identifier exists. It's like testing if a person identifier exists."

Hint 1:
" It involves the action EDPPO."

Hint 2:
" Testing a person identifier uses the flag -PERS. For projects the flag is -PROJ."

Hint 3:
" The final flag to EDPPO is -L, as in the previous case."

6. Conclusion

The tutorial and assessment strategies include a variety of approaches to the material to be taught. Successive refinement providing a top-down overview approach to procedures; Cognitive apprenticeship providing a bottom-up, imitation-oriented method; Discovery learning emphasising similarities between procedures where they exist and encouraging the spontaneous generalisation of skills; Abstraction generalising from the conceptual information to encourage links across tasks. The latter two strategies both promote elaboration and deeper processing of the skills encouraging better memory for the procedure. Socratic diagnosis provides a debugging approach to error analysis; direct assessment gives a traditional and familiar question and answer routine; and finally Discovery assessment and Practice test the fundamental skill: the students ability to actually perform the task correctly.

In addition to these strategies the revision facility allows the student to recap at any stage on any topic that they may have forgotten, and allows the student to request reteaching in specific areas and the browse function enables students to look ahead if they wish. These give the student a significant amount of control over the interaction.

Dominie's eight tutorial and assessment strategies allow for a large degree of

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flexibility, and multiple approaches to both the teaching and assessment of both procedural and conceptual material. Dominie allows the student to take the initiative in choosing whether to be taught or assessed, and gives her the option of revising or browsing through any of the material at any stage, and the facility to quit the system at any point. The student can progress at her own level within a number of the strategies, by requesting further conceptual information within cognitive apprenticeship, or requesting a detailed text when presented with a summary, or by recapping material at any point. It also allows students to mark procedures for reteaching if they have forgotten information, or recognised a misconception.

Due to the granularity of the control structure the model of the student is updated after every small step. This allows Dominie to be responsive to student performance, as well as to reports of their own short term states. If the student is not doing well on assessments, or indicates confusion Dominie automatically enters a reteach phases, so that she does not compound her confusion. Reteaching is controlled so that the same area will not be retaught more than once at any one time, so the student does not enter a frustrating loop when she cannot produce the answer.

The tutorial and assessment strategies in Dominie give the student a large degree of flexibility in the tutorial session while remaining within limits that enable the user to feel confident and well supported.

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Appendix 1

Glossary of terms

Actions - A sequence of interface tasks associated with a procedure. Carrying out these tasks after successful execution of the conditions results in the sucessful execution of the procedure.

Basic procedure - A procedure which has no conditions, ie. which can simply be executed.

Concept - A collection of declarative information grouped around a particular entity in the underlying domain.

Conditions - A set of procedure names within a procedure. The conditions represent goals which must be carried out. In this sense they are subgoals of the procedure, but preconditions of the action part of the procedure.

Goal - A procedure within the context of a particular plan

Interface action - The simplest unit of representation of the interface, for example, a click of the mouse button..

Interface task - One or more interface actions which represent the smallest indivisible action sequence used by the planner.

Plan - A collection of procedures ordered into a tree structure. Within this tree structure the procedures are regarded as goals.

Post-tests - An interaction or sequence of interactions with the user which determines which plan to follow when alternatives exist. These only occur in plans where there are disjunctive choice points.

Procedure - The smallest unit of knowledge about procedural aspects of the process of using the interface.

Task - The name of a procedure occuring on the task list. This is used to specify the highest level goal of an activity which the student is to learn. In this context the procedure is called a task.

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List of Technical Reports

These reports may be obtained from:-

Hansa Solanki, Institute of Educational Technology, The Open University,
Walton Hall, MILTON KEYNES, MK7 6AA, England.

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1	M.A. Bramer (1980) Using Computers in Distance Education: The first ten years of the British Open University.
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